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ORGDP HISTORICAL INVENTORY DIFFERENCES FOR PERIOD 9/9/44 THROUGH 9/30/83

Compiled by
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Environmental Management Division
OAK RIDGE K-25 SITE
for the Health Studies Agreement

November 30, 1995

Oak Ridge K-25 Site
Oak Ridge, Tennessee 37831-7314
managed by
LOCKHEED MARTIN ENERGY SYSTEMS, INC.
for the U.S. DEPARTMENT OF ENERGY
under Contract DE-AC05-84OR21400

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ABSTRACT

This report has been prepared at the request of the Department of Energy as an evaluation of the ORGDP uranium and uranium-235 inventory difference, its development over the 39-year plant history, and an explanation of why the inventory difference cannot be zero.

TABLE OF CONTENTS

XI. APPENDIX

I. SUMMARY AND CONCLUSIONS

As of September 30, 1983, nuclear material receipts at the ORGDP amounted to 232,441,523 kilograms uranium and 2,118,775 kilograms uranium-235. Of this total amount received over the 39-year history of plant operation, 99.96 percent of the uranium and 99.93 percent of the uranium-235 have been accounted for by way of transfer of material off site, plant inventories, and the estimated quantities of material. As of the same date, the cumulative 39-year ORGDP inventory difference (ID) was 167,930 kilograms uranium and 4,812 kilograms uranium-235 (see Table 1). Of this total, 89,529 kilograms uranium and 645 kilograms uranium-235 (over 50 percent of the total ORGDP historical uranium ID) can be attributed to the feed manufacturing and development facilities. The materials involved were either depleted, normal, or only slightly enriched (less than 1.0 percent).

Good

Discussions will be presented describing operational problems in these facilities which precluded the use of precise accountability methods. These problems include:

- The startup and debugging operation involving repeated outages of processing equipment;
- Dismantling, cleanout, repair, and revision of this equipment;
- The removal of large quantities of partially reacted uranium products from this equipment; and
- The discard of decontamination and cleanout materials.

As a result of these operating problems, material losses have occurred.

Data in Table 2 derived from monitoring of selected plant environmental areas, indicate and confirm that major portions of these materials can be categorized as part of the feed plant ID. These areas are:

- Monitored discharged quantities to Poplar Creek are shown to contain 10,999 kilograms uranium.
- The ground near the feed plant shown to contain approximately 191 kilograms uranium.
- The loss by vent to atmosphere of approximately 6,822 kilograms uranium.

Other noncascade ID quantities as shown in Table 1 for such areas as feed, development, recovery, decontamination, and miscellaneous.

At the end of September 1983, the cascade cumulative ID was 78,933 kilograms uranium and 4,234 kilograms uranium-235. This represents approximately 47 percent of the total ORGDP historical uranium ID and 88 percent of the total historical uranium-235 ID. When these values are adjusted for the hidden inventory estimates and for the cylinder heel dilution quantities from Table 2, these ID quantities are reduced to a residual 63,417 kilograms uranium and 2,603 kilograms uranium-235. When compared to total cascade feeds over the 39-year period of 206,353,541 kilograms uranium and 1,832,962 kilograms uranium-235, these residual ID values are on a percentage basis, respectively 0.031

percent and 0.142 percent. These percentage ID values, when looked at another way, represent accounting efficiencies of 99.97 percent and 99.86 percent, which are judged to be quite good. Factors that may have contributed to the residual cascade ID include variable biases in the complex measurement systems employed for this material balance, such as:

- Biases in equipment flow characteristics used in inventory determinations;
- Biases in pressure, temperature and line recorder instrumentation;
- Bias errors in equipment volumes;
- Gradient sampling errors;
- Bias in measurements used for cascade feed and withdrawals have contributed to this ID through the uncertainty in the value assigned to the assay of normal UF_6;
- Small consistent biases in scales used to weigh cylinders of UF_6; and
- Small consistent biases in obtaining samples of feeds and withdrawals from the cascade.

Other contributing factors may be unknown or unmeasured releases of uranium material from the cascade balance area and the underestimation of material deposited on the internal surfaces of cascade equipment.

In retrospect, the material balance experience at this installation is, in our judgment, considered to be good. This judgment is based on accounting efficiencies of 99.96 percent for uranium and 99.93 percent for uranium-235 which have been demonstrated over the 39-year operating history of the ORGDP.

It is noteworthy that the major portion of the material discard and release activity occurred during the period 1950 to 1965 when the standards for discarding industrial materials to the environment were not the same as present day standards. Operating standards and procedures today are more stringent, and certain practices of the past would not be permitted today at this plant.

II. INTRODUCTION

A. The Process

The primary mission of the Oak Ridge Gaseous Diffusion Plant is to produce uranium enriched in the isotope uranium-235. Analogous to a distillation process, normal, partially depleted, and slightly enriched uranium hexafluoride (UF_6) in the form of a gas is fed into the gaseous diffusion cascade which, through a series of separating stages, enriches the uranium hexafluoride in the isotope uranium-235, ultimately producing UF_6 with higher concentration of uranium-235 at the top of the plant and discharging UF_6 depleted in the uranium-235 isotope at the bottom of the plant. UF_6, the process gas, is a toxic and highly corrosive material requiring special care in material handling procedures and specialized technology in construction of plant facilities.

A stage is the basic unit of the diffusion plant consisting of a container to house the barrier (the medium of isotope separation), the necessary gas pumping equipment to move the UF_6, process gas coolers, and the appropriate controllers to maintain required process operating conditions. Since the degree of uranium-235 enrichment in a single stage of the plant is very small, extensive enrichment can be obtained only through the employment of a very large number of separating stages operating in series. Multistage processing plants are commonly called cascades; therefore, the multistage isotopic separations plant is known as the gaseous diffusion cascade.

At the gaseous diffusion plant, extensive facilities must be provided for the maintenance of plant equipment. All of the equipment which has been in production operations contains surface contamination or uranium compound deposits formed by the reaction of the internal surfaces of the plant or wet air with the corrosive process gas. This equipment is operated below atmospheric pressure. Equipment is heated in place with a chemical solution, but when necessary the equipment is removed and taken to the decontamination facility, there the surface contamination and uranium compound deposits are removed from the internal surfaces of plant equipment prior to performing extensive maintenance work. This removal is usually accomplished through the chemical scrubbing of the equipment, through an acid or caustic solution spray in booths, and subsequent water spray rinses. Recovery of the acid or caustic cleaning material and rinse water are pumped to storage columns where they are stored and sampled to determine their economic value before shipping to National Lead of Ohio (NLO). Fernald

Solid materials are now blended to a nominal assay of 0.9 percent and shipped to NLO for recovery.

Feed manufacturing facilities were formerly located and in production at the ORGDP site. Starting material in the form of uranium trioxide was fed to a series of vibrating tray reactors where the compound was reduced to the dioxide form by exposure to hydrogen. Uranium dioxide, in turn, was reacted to uranium tetrafluoride by exposure to hydrogen fluoride. Uranium tetrafluoride was converted to the hexafluoride form by reaction with fluorine and the resultant uranium hexafluoride was trapped in chilled equipment commonly referred to as cold traps. Subsequently, each cold trap was heated and the trapped UF_6 was liquified and drained to shipping containers. The feed manufacturing facility was later revised by replacing the series of vibrating trays with fluid bed tower reactors.

B. The Material Balance Concept

Similar to bank balance

Material balance in accounting can be defined by the mathematical formula:

Beginning Inventory + Receipts - Shipments - Ending Inventory = Inventory Differences (IDs)

It should be emphasized that ID does not necessarily imply material lost or stolen; for the most part, ID simply means a quantity of material not discernible by the usual means of measurement of detection due to some phenomenon. As is frequently the case, those phenomena can be a time dependent function and may require months or even years to become revealed and quantified as a contributor to an ID. In the idealistic sense it would appear that a zero value for IDs would be possible and desirable; however, in the practical sense, this is almost never the case. The material balance and ID concepts are not unique to the uranium processing industry. Whether the material balance is applicable to a uranium processing facility or to a petroleum or even a precious metal processing

Generic

facility the concepts of material balance and ID are applicable and the ID is almost never zero. The subject of this report is the evaluation of the ORGDP uranium and uranium-235 ID, its development over a 39-year period, and why in practice it cannot be zero.

Generic

C. Material Balances - General Discussion

In the preparation of this report, data were obtained from the best available records for the 39-year span of plant operation. Interpretation of data is from the relatively few knowledgeable individuals who are familiar with plant operations over this entire time period and who are still available to supply relevant information.

It is of interest that almost coincidental with the beginning of operation in the K-25 and K-27 Buildings in 1945, substantial effort was devoted to the development of inventory values and maintenance of material balances even to the extent of daily values. It can also be noted that some time prior to October 17, 1947, an AEC (now DOE) audit team was on site to survey the accounting control maintained over uranium material at the ORGDP at six-month intervals and later at intervals of one year. The ORGDP uranium accounting and control function has been reviewed at least annually by responsible government personnel since the first full year of operation over 35 years ago. As evidenced by the reports of the survey teams, DOE has been kept fully informed of those major

Generic

problems and operating considerations having impact on the material balances and hence the ID; also, the contractor has, for the most part, received favorable evaluation on the materials management and control responsibilities.

It should be emphasized that no new information on IDs is provided in this report. As stated previously, all major problems and all relevant material control information and data have at one time or another been communicated to appropriate DOE personnel through discussions during survey and audit periods. The major purpose of this report is that of collecting all major relevant material in one document as opposed to a series of monthly or quarterly reports issued over a 39-year period.

What is a balance area

III. THE ORGDP HISTORICAL INVENTORY DIFFERENCE

Exhibited in Table 1 is the cumulative IDs for the designated balance areas that have been active in the processing for 39 years. These designated areas shown were those having historical ID values of some significance. For each balance area, the cumulative uranium and uranium-235 ID, and average ID assay are given. Also included is the operational status of each balance area, startup dates, and, where applicable, dates of shutdown or deactivation. For the purpose of this report, September 30, 1983 was selected as a convenient point of termination for cumulative ID calculations, accounting memorandum, and evaluations.

Shown in Table 2 are estimated quantities of known deposits of uranium material deposited on the internal surfaces of plant equipment or in the plant environs. These material deposits, which have occurred as a result of plant operations and which contribute to the plant cumulative IDs, are estimated primarily for the purpose of explaining cumulative ID. The uncertainty of the methods of measuring (estimating) these quantities, however, precludes the use of these values in accounting records.

From the date of the first receipt of uranium hexafluoride at the ORGDP site, September 9, 1944, through the end of September 1983, receipts totaled 232,441,523 kilograms uranium and 2,118,775 kilograms uranium-235.

Table 3 depicts the yearly receipts. Table 4 is a summary of inventory differences by grams. Table 5 is a plot of the ratio of total uranium ID to off-area receipts. Table 6 is a plot of ratio of U-235 ID to off-area receipts.

IV. FACILITY OPERATIONS - A CHRONOLOGY

A history of operations at the ORGDP can logically be divided into three major periods; early cascade growth and operation 1945 through 1949, expansion period 1950 through 1954, and the toll enrichment and cascade improvement period 1955 to present. Each period can be characterized by significant events including events having impact on the plant material balance. Shown in Table 7 are compilations of those events considered most significant and having greatest impact on plant operations and, hence, the material balance.

A. Early Cascade Growth Period

The early cascade growth period deals primarily with the construction and initial operation of a new technological endeavor, the Oak Ridge Gaseous Diffusion Plant. The most significant events of this period were:

- The placing in operation of the K-25 and K-27 plants;
- The production of top product at enrichments exceeding 93.0 weight percent uranium-235;
- The confirmation of internal corrosion of plant surfaces by UF_6;
- The recognition of the molecular exchange phenomonen and the resulting effect on material balances and production;
- The recognition of problems of obtaining a dynamic inventory of the cascade.

In this period, material balance efforts were begun right from the beginning, even to the extent of daily cascade material balances, and monthly material balance reports were issued for the cascade, the laboratory, decontamination, recovery, UF_6 conversion and storage accounts.

During this same period, Benedict and Squires[1] provided consultant service to the AEC on material balance problems and semiannual uranium accountability audits were begun by personnel from the newly formed AEC. Plant laboratory work was in progress on improving uranium analytical methods in the development of the first acceptable isotopic standards for all ranges of uranium-235 enrichment. These isotopic standards were ultimately to be used throughout the nuclear industry. In the development and research laboratories extensive work was under way to ascertain uranium hexafluoride corrosion data on a wide range of materials used in the construction of the gaseous diffusion plant.

Material losses during this period were relatively small and were probably the result of corrosion on the internal surfaces of K-25 and K-27 equipment. Uranium-235 balances were complicated by the uncertain value of isotopic concentration in normal feed materials. Equipment stabilization efforts to combat the corrosion problem were emphasized to ascertain rates of corrosion and to determine cause and effect relationships.

[1] *Uranium Material Accounting at the Gaseous Diffusion Plant,* SECRET, May 3, 1948, Benedict and Squires.

On the weekend of July 2, 1950, a complete cascade power failure occurred. Motors and seals failed and wet air inleakage plugged the barrier. Extensive contamination of carbon and alumina traps on the cascade seal and purge systems occurred. By July 20, 1950, the cascade was remade and was operating at 97 percent efficiency. In the fall of 1950, the feed manufacturing facility was placed in operation. This facility experienced many operating problems resulting in unmeasured releases of UF_6 to the atmosphere, loss of uranium as UO_3 and UF_4 to the environment, and the discard of decontamination solution, resulting from the cleaning of feed plant equipment, to holding ponds and subsequently to Poplar Creek.

Generic (GDP)

In the early 1950's the nuclear material control philosophy was considerably different from present day philosophy. Since the feed plant facility was the first large-scale continuous UF_6 production plant, much of the operation involved development, pilot plant, and field testing of processing equipment for fluorine, hydrogen fluoride and UF_6 service. The resulting startup and debugging operations involved repeated outages, including dismantling, cleanout, repair and revision of processing equipment, such as reaction vessels, screw conveyors, ash receivers, valves, and piping. Since the process involved handling tons of normal assay uranium, these operational startup problems resulted in uranium accountability difficulties with priority emphasis on solving operational problems to meet production schedules.

Decontamination data results from cascade equipment removal were studied but no conclusive answers were obtained to evaluate hidden inventory. Based on stabilization tests and laboratory data, initial hidden inventory estimates were calculated periodically and utilized to assess the cascade inventory differences.

During this period, a barrier manufacturing facility was established to provide an improved barrier for installation in the K-25 and K-27 buildings. Improved barrier was installed in these buildings and during this time an initial inspection or process equipment which had been in plant service for an appreciable time period was accomplished. Decontamination and recovery facilities were considered inadequate for the program and estimates of hidden inventory derived from production data were inconclusive. During January 1949, the isotopic value of normal uranium hexafluoride was finally established at 0.7115 wt. percent uranium-235; however, on January 1, 1966, by publication in the Federal Register, the U.S. Government established the value of normal uranium at 0.711 wt. percent uranium-235 for all official transactions. In this same period the first attempt to establish the reproducibility of the cascade inventory was accomplished by taking multiple inventories within a 24-hour period.

B. Expansion Period

The period 1950 through 1954 was the most significant with respect to large scale activities which resulted in an impact on the plant material balance.

Large quantities of partially reacted uranium products were removed from the processing equipment followed by decontamination, interim storage, and discard of cleanout materials, which were not accurately identified and measured. For example, liquid and gaseous effluents from the facility were not monitored during this period. As a result of these operating practices during the startup period in the 1950's significant uranium material losses may have occurred.

*

Consistent w/ * on p 32?

This facility operated until late 1961 when the operation was discontinued for lack of sufficient demand for operation of both the ORGDP and Paducah feed plants.

The most significant operational event of this period was the design, construction, and placing in operation of the buildings K-29, K-31, and K-33. A significant increase in cascade ID? during the startup of these buildings was attributed to the adherence of inventory on the internal surfaces of new plant equipment.

An additional series of major events impacting on the plant material balances were a barrier change-out program for K-29 in 1952, and the establishment of the K-1420 decontamination, recovery, and UF_6 conversion facility. What is it? During this barrier change-out project a second opportunity occurred to inspect the internal surfaces of cascade equipment which has seen extensive UF_6 service. Production data from the K-1420 decontamination of K-29 equipment, together with equipment length of service, provided the basis for establishing consumption rates for the cascade addition. Some of these data form the basis for hidden inventory values exhibited in Table 2.

C. Toll Enrichment and Improvement Period (1955 to Present)

The most significant event of this period was the transition of the gaseous diffusion production facility from supplying enriched uranium for military use to supplying enriched material for the newly emerging Civilian Power Reactor Program. This transition extended over a period that was characterized by variable power usage and the expiration of power contracts, the placing in standby of large segments of cascade equipment and the stockpiling of production for future use in the Toll Enriching Program. Power usage dropped from a high of 2,285 Mw experienced in early 1952 to a low of 460 Mw in the early 1970's. Also, during this period the original gaseous diffusion plant buildings, K-25 and K-27, were shut down and buffered with dry air and/or nitrogen and placed in standby. During the succeeding years, the Paducah and Portsmouth plants have made extensive use of the instruments, valves, and piping salvaged from these buildings. It is important to note that uranium corrosion products still remain in this shutdown equipment. All studies to date indicate that the cost of dismantling the shutdown equipment exceeds the salvage value of the equipment including the recovery of the uranium.

Was equip. cleaned out? yes

During this same period, the shutdown of the feed manufacturing facility also occurred. However, in March 1962 the feed plant was reactivated with modified equipment for a three-year period to produce UF_6 from slightly enriched uranium tetrafluoride. Other milestones occurring in this period were:

- A barrier replacement program for K-31;

Closed out.

- The deactivation of the K-1420 UF_6 conversion facility in mid-1965;
- The official beginning of the Toll Enriching Program in January 1969; and
- The start of the Cascade Improvement Program (CIP/CUP) in 1975.
- The completion of the CIP/CUP in 1981.

One additional UF_6 release incident during this period was the failure of certain equipment in August 1971, in the K-311-1 purge cascade. This incident resulted in an amount of wet air inleakage to the cascade causing additional equipment failures and the interruption of normal cascade operation for several weeks. It is likely that deposition of uranium on internal surfaces of the plant equipment was increased during this period.

V. CASCADE MATERIAL BALANCE (ID)

Generic

In our opinion, after many years of investigative work with this material balance, the cumulative ID is the result of undetected biases in the measurement systems employed, undetected and unmeasured gaseous releases from the cascade material balance area, and unmeasured uranium deposits on the internal surfaces of cascade equipment. These biases and unmeasured releases cannot be quantified and the deposits can only be imprecisely estimated by indirect methods. Given the size and complexity of the system and the variability of operating conditions over the history of the plant, we believe it is impossible to assume that steady state conditions and process homogeneity have existed so that long-term definitive studies and evaluation of the above noted sources of ID could be made. Biases in measurements may, in fact, become variable biases when considering a particular variation in process operations, such as changes in power levels, pressures and temperatures. Biases in equipment flow characteristics used for inventory determination may also change with operating levels. Variable biases of these types cannot be evaluated and the resulting impact on material balances cannot be quantified.

All cascade stacks are routinely measured for flow and uranium concentration. Failed equipment, equipment scheduled for preventive maintenance, and contaminated equipment removed for improvement go through the decontamination process. The resulting decontamination production is credited back to the cascade after measuring or estimating the uranium content.

As part of the discussion of the cascade material balance, a section on important factors affecting this balance is included. These factors are: the cascade inventory and the cascade streams. These discussions are included to indicate the level of effort expended in establishing accountability for this operation and in attempting to evaluate the causes and ID quantities.

A. Cascade Inventory

One major component of the cascade balance area which has received considerable attention is the cascade in-process inventory. This operation is inventoried while "onstream" and with the inventory in the gas phase through suitable application of the universal gas law. The physical inventory of a gaseous diffusion plant represents a unique problem because the "in-process" material is in constant flow and cannot be interrupted for any direct method of measurement such as weighing. Practical considerations have made it necessary to reject any thought of shutting down the cascade for inventory purposes. This is based on the excessive time element that would be required with its very high cost in loss production, isotopic mixing losses, and potential equipment damage from shutdown and startup activities. Calculations of the gas phase UF_6 are based upon approximately 6,600 pieces of data, which include more than 5,000 directly associated with the basic cascade; that is, readings of process pressures, stage temperatures, laboratory assays, and gas chromatograph results. The other readings come from auxiliary systems such as pressures and temperatures and analyses of gas in storage drums and inter-plant lines.

Generic

Generic

computer model

These data are used in a series of equations which describe material flow through the equipment. The accuracy of these equations is dependent upon:

- The internal volumes of all pieces of equipment and associated piping; and
- A series of coefficients based upon empirical tests accomplished in the ORGDP test loop facility.

In a typical inventory, operators take data readings on the last shift of each month beginning at approximately 6:00 p.m. and ending at midnight. The data are processed by computer, resulting in a plant in-process uranium and uranium-235 inventory.

Besides the obvious potential for incorrect readings and transcribing, other areas which can introduce a ID are:

- Unaccounted for alterations in equipment or piping configurations which affect volumes;
- Possible inventory equation errors or biases;
- Cascade transients (the cascade is not stable while inventory readings are being taken).

B. Cascade Streams

One other major component of the cascade materia balance and thus the ID is the flow of uranium into and from the cascade. During the early years of plant operation, feeds were received from the Harshaw Chemical Company in 400-pound cylinders, and product was withdrawn in "always safe" cylinders that held one day's production.

The depleted stream from the bottom of the plant was withdrawn into 30-inch cylinders of the 2.5-ton chlorine-type cylinder. During the intervening years, and with changes in standards of nuclear safety and improved handling equipment, cylinder sizes were changed so that today feeds are received in 10- and 14-ton capacity cylinders, product is withdrawn in 10-ton cylinders, which is subsequently drained to 30-inch cylinders for shipment and the depleted steam is withdrawn into 14-ton cylinders.

Measurement error for most of these material flows is considered to be random and these measurement systems are, for the most part, subject to quality control techniques. One problem in this area is the probable bias in the K-1131 scale used to weigh tails. Presently, ORGDP has purchased an ORBITRAN scale to accommodate most of this bias.

VI. NONCASCADE MATERIAL BALANCES ID

When reference is made to Table 1, it is apparent that the feed manufacturing facility, including both campaigns and the feed manufacturing development activity account for over 50 percent of the total ORGDP inventory differences. These two balance areas combined exhibit losses of 89,529 ? kilograms uranium and 645 ? kilograms uranium-235 over a 15-year span; the average assay is 0.70 percent confirming the relatively low assay of the operations. During the span of these operations, the primary emphasis was to produce UF_6 with accountability activities being secondary. As previously described, extensive operations difficulties were experienced which hampered accountability measures at that time. Although it is not possible to apportion the quantities, significant portions of those noncascade items listed in Table 2 were attributed to feed manufacturing facility.

Weigh it + out

Alumina traps &

Varied containers samplings

The decontamination facilities show a gain over their lifetime of operations where the values indicate the amount of material removed from contaminated equipment. These amounts are credited to their source, such as the cascade, where applicable.

How can this be?

The recovery balance area to date shows a gain in uranium and a loss in uranium-235. Volume in measurements used ? or unmeasured flows to this area are considered the sources of these inventory differences.

Other areas indicating losses of any magnitude are included in miscellaneous. During the many years of operation, there have been several instances where the liquid contents of a drum in the storage areas have corroded through the bottom of the container and probably discharged to the storm sewers although efforts were made to recover some of the material through decontamination techniques. A circumstance of this nature occurred when the ORGDP was requested to store miscellaneous nuclear compounds sent to the Oak Ridge area from many locations throughout the United States. As was often the case, the material was received into accountability using the shipper's values, since sampling of these materials would frequently have been impossible or hazardous. Several thousands of containers were included in this category. Since recovery methods for much of this material were unknown at the time, the material was held in long-term storage pending disposition. The corrosion of the container frequently occurred during this long storage period with a subsequent loss of material.

In addition to the storage area containers, many other containers lost their identity and the identity of their contents during this long-term storage and were discarded, usually by burial, in approved sites within the controlled area for safety considerations. Estimates of discarded amounts submitted for write-off of this material could have been in error.

At the present time there are no known discharges or plant effluents which are not monitored for uranium content. Laundry operations are not monitored per se; however, sanitary sewer discharges are, and it is probable that the laundry contributed to the estimated one pound of uranium per year discharged from this source.

As indicated in the discussion for the cascade, all waste material burials, contaminated equipment, and controlled discharges are measured for uranium content.

VII. LABORATORY

Generic

In general, uranium in uranium hexafluoride was measured by two gravimetic methods: nickel knock-out method using about 100 g subsamples, and the P-10 method using about 10 g samples. Isotopic analyses for uranium-235 in uranium hexafluoride was performed by gas-phase, relative mass spectrometry. The estimates for these measurements are based on final results of sample analyses and are dependent on the precision of the mass spectrometer and the number of determinations performed. Uranium in solids and solutions were generally performed by a variety of methods, the principal of which are listed with estimated precisions, along with the methods used for isotopic uranium-235 (see Table 8). No known long-term biases were presented and none were known to exist.

VIII. STATISTICAL ANALYSIS OF INVENTORY DIFFERENCES

The cumulative uranium and U-235 inventory differences for 1946-1983 were statistically analyzed for significant trends. Data investigated included total plant, cascade, and feed plant inventory differences for both uranium and U-235 (Table 9). Significant changes of trends were detected in the data, and these are outlined below.

The total plant uranium inventory was divided into five time periods according to changes in trends detected by statistical tests. These five division were 1946-1951, 1952-1960, 1961-1968, 1969-1974, and 1975-1983. The data in each of these time periods showed a statistically significant slope (i.e. slope not equal to zero). The U-235 inventory difference data were then investigated to see if these data exhibited similar changes to the uranium data. For the most part, the U-235 data and uranium data fell into the same time periods; however, there a few points that are questionable if they fit into either time period. The U-235 data in each of the five divisions also showed a statistically significant slope. The data for 1964 were omitted from both uranium and U-235 in establishing slopes. These slopes are summarized for both uranium and U-235 in Table 10.

The cascade inventory difference were then analyzed similarly for uranium and U-235. These data fell into the previously established time periods fairly well. The uranium data did not fit into the 1975-1983 time period and further divided into two periods: 1975-1978 and 1979-1983. The uranium data in four of the now six time periods showed a slope significantly different from zero. Note, the U-235 slope in the 1961-1968 time period is negative. The 1964 data were omitted from both uranium and U-235 in establishing slopes. These slopes are summarized in Table 9.

Finally, the feed plant inventory difference data were similarly analyzed. These data were available on a monthly basis, but it was difficult to detect trends of length. The data were computed for year-end results and analyzed accordingly. The feed plant data were for 1950-1966 so only three of the previously established time periods were involved. Except for a couple of points (1958 and 1959) and the last four, one trend line fit the data well and one slope was computed for each of uranium and U-235. These are summarized in Table 9.

Table 10 depicts the cumulative, cascade, and feed plant uranium inventory difference for the years 1946-1983, showing the five time periods. Similarly, Table 11 is a plot of U-235 inventory differences.

IX. ENVIRONMENTAL MONITORING

Environmental monitoring for uranium was limited before 1971, with no samples being collected on a routine basis but accountability of uranium has always been routinely documented.

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In 1971 the Environmental Policy of ORGDP was developed; therefore, from 1971 to present, air and water discharges have been monitored on a routine basis for total uranium concentration as well as assay determination. The water discharges, which are monitored weekly, include: K-1407-B Holding Pond which eminates from the K-1420 Decontamination Facility; K-901-A which consists of the blowdown from the Recirculating Water System; K-1203 Sewage Treatment Plant; K-1004B which receives laboratory waste; K-1700 Holding Pond; and K-1515 which settles out solids from the K-1515 Sanitary Water Treatment Plant. The air discharge which is monitored on a daily basis is located at the K-402-9 KOH scrubber. Samples are collected and analyzed for total uranium. Weekly, air samples are collected from samples stationed around the perimeter of ORGDP and are analyzed for total uranium.

In and around the ORGDP facility, miscellaneous samples are collected and analyzed for total uranium. These area's include Poplar Creek sediments (two years), soil and vegetation (two years), and deep wells (two years).

X. SECURITY

Plant policy is to provide appropriate security measures for prevention of diversion of nuclear materials consistent with the DOE regulations relating thereto.

good

Physical Layout--the map (Table 12) is a plan drawing of the ORGDP layout which is useful in developing an understanding of the physical security controls, as well as other aspects of the diversion control problem.

The entire plant area is enclosed by a security perimeter fence which is illuminated during night hours and patrolled by armed security inspectors. All personnel entering the security area either hold a DOE "Q" clearance or are escorted by "Q" cleared employees. All packages and official vehicles entering or leaving the plant area are subject to search.

The prime interest of the security measures is to protect special nuclear materials against theft. The form of the material and the containers provide substantial protection against sabotage, and considerable planning and effort would have to be expended to remove a cylinder from the site. The defense against such acts, of course, is the security inspectors. During the day shift, a large complement of security inspectors is on duty. The evening and night shifts have an adequate force of security inspectors and officers. Three interior patrols and one outside patrol survey the perimeter boundary during night hours.

The remaining inspectors are on duty at the portals or are interior site inspectors. The inspectors are trained and fully qualified to respond to any on site emergency. Close liaison is maintained with the other two plants, and with local law enforcement agencies and federal authorities.

Table 1

Cumulative ORGDP
Material Balance Area ID
1944 Through September 1983

How did they get this Divide

Balance Area	Kilograms Uranium	Kilograms U-235	Average Assay%	Operational From	Operational To
Cascade	78,933	4,234	5.36	1945	1983
Feed Plant:					
Normal/Depleted	~~77,113~~ 58,853	~~584~~ 422	0.76	10/50	7/61*
Enriched	18,280	162	0.90	4/62	7/65*
Development (Feed Mfg.)	12,416	61	0.49	12/47	7/72*
Recovery	2,938 Cr	157		1947	1983
Decontamination	13,043 Cr	230 Cr	1.76	1946	1983
Miscellaneous	15,449	6	--	1946	1983
Plant**	167,930	4,812	ok		

*Deactivated
**Plant totals will not equal sum of balance area or assay range due to rounding and the ommission of several nonsignificant items such as variance or privately owned accounts. ?

58833
18280
12416
89,529

Table 2

Accounting Memorandum
Estimated Contributors to ID
Cumulative Through September 1983

? Environment (Ruth C is looking into his environ. table a la PGDP

Location of Deposit ~~or Source of Hidden Inventory~~	Kilograms Uranium	U-235
K-1407-C Holding Pond	7,200.0	114.5
Uncredited contamination on drums sent to burial	225.0	1.5
Poplar Creek bed contamination (within plant boundaries)*	10,999.0	119.2
Ground near Feed Plant*	191.0	1.3
Losses by vent to atmosphere**	6,822.0	49.1
Cylinder cleans ~~heel dilution prior to~~ July 1955	--	179.2
Sanitary sewer discharges	13.6	0.2
TOTAL	25,450.6	465.0

*Values based on core samples analyzed for uranium and uranium-235.

**Based on vent flow rates and uranium analysis of samples of the gas stream.

Table 3

TOTAL OFF AREA RECEIPTS FROM 1944 THROUGH SEPTEMBER 30, 1983

YEAR		Kilograms Uranium	U-235
1944 thru 1946		986,350	7,187
1947		628,993	4,453
1948		790,592	5,580
1949		679,704	4,861
1950		1,216,821	8,772
1951		392,383	2,834
1952		1,720,689	12,179
1953		4,749,238	35,327
1954		5,372,703	59,683
1955		4,848,517	48,243
1956		7,925,021	65,564
1957		8,528,123	68,192
1958		8,210,647	75,901
1959		7,791,986	77,895
1960		6,845,692	71,720
1961		7,004,798	74,202
1962		5,624,451	72,313
1963		4,423,744	55,361
1964		5,823,043	53,501
1965		7,661,407	39,001
1966		7,552,111	48,883
1967		7,980,663	39,812
1968		5,812,311	35,878
1969		5,006,602	46,016
1970		6,004,430	52,782
1971		6,917,038	62,403
1972	FZA	3,099,873	42,296
1972	BWA	3,542,489	61,505
1973	FZA	1,796,805	7,238
1973	BWA	5,945,271	60,772

Table 3 (Continued)

YEAR		Kilograms Uranium	U-235
1974	FZA	2,336,620	10,157
1974	BWA	6,827,502	70,126
1975	FZA	693,887	7,668
1975	BWA	6,772,427	69,512
A 1976	FZA	4,430,827	13,681
B 1976	FZA	1,043,518	3,323
A 1976	BWA	3,344,690	72,763
B 1976	BWA	1,441,039	17,971
1977	FZA	4,078,283	12,432
1977	BWA	6,898,562	75,731
1978	FZA	2,050,286	13,493
1978	BWA	5,838,275	56,041
1979	FZA	352,429	9,600
1979	BWA	8,503,215	77,483
1980	FZA	295,674	8,718
1980	BWA	7,529,213	65,038
1981	FZA	285,546	7,381
1981	BWA	7,968,079	67,817
1982	FZA	423,825	12,165
1982	BWA	8,313,857	70,067
1983	FZA	417,793	10,470
1983	BWA	7,713,481	66,784
	TOTALS	232,441,523	2,118,775

Table 4

ORGDP ID BY YEAR

GRAMS

YEAR	ORGDP TOTAL Uranium	ORGDP TOTAL U-235	CUMULATIVE PLANT Uranium	CUMULATIVE PLANT U-235
1946	5,035,860	145,240	5,035,860	145,240
1947	281,039	93,301	5,316,899	238,541
1948	785,902	91,089	6,102,801	329,630
1949	-48,953	47,468	6,053,848	377,098
1950	2,123,494	154,423	8,177,342	531,521
1951	1,690,727	84,100	9,868,069	615,621
1952	16,546,057	262,579	26,414,126	878,200
1953	4,160,168	185,141	30,574,294	1,063,341
1954	13,370,268	482,621	43,944,562	1,545,962
1955	11,661,250	309,518	55,605,812	1,855,480
1956	8,536,017	117,887	64,141,829	1,973,367
1957	15,246,090	367,195	79,387,919	2,340,562
1958	10,105,588	337,069	89,493,507	2,677,631
1959	15,868,847	286,105	105,362,354	2,963,736
1960	2,299,795	213,424	107,662,149	3,177,160
1961	13,580,630	456,033	121,242,779	3,633,193
1962	5,439,483	105,119	126,682,262	3,738,312
1963	5,569,726	-83,118	132,251,988	3,655,194
1964	3,549,104	-140,351	135,801,092	3,514,843
1965	6,683,590	287,370	142,484,682	3,802,213
1966	6,223,279	57,112	148,707,961	3,859,325
1967	2,110,944	-19,832	150,818,905	3,839,493
1968	-305,421	-54,039	150,513,484	3,785,454
1969	10,665,076	220,171	161,178,560	4,005,625
1970	878,298	21,215	162,056,858	4,026,840
1971	-893,889	48,122	161,162,969	4,074,962
1972	3,201,744	130,370	164,364,713	4,205,332
1973	4,052,593	74,741	168,417,306	4,280,073
1974	1,260,889	217,870	169,678,195	4,497,943
1975	-4,771,094	-56,339	164,907,101	4,441,604
1976 A	-6,888,540	-143,022	158,018,561	4,298,582
1976 B	3,995,276	117,998	162,013,837	4,416,580
1977	-5,647,632	-13,090	156,366,205	4,403,490
1978	5,939,360	60,672	162,305,565	4,464,162
1979	-4,404,317	14,407	157,901,248	4,478,569
1980	1,769,262	112,126	159,670,510	4,590,695
1981	6,297,868	61,268	165,968,378	4,651,963
1982	264,875	169,753	166,233,253	4,821,716
1983	1,696,925	-9,542	167,930,178	4,812,174

TABLE 5

RATIO OF TOTAL URANIUM ID TO OFF AREA RECEIPTS
FOR 1946–1983

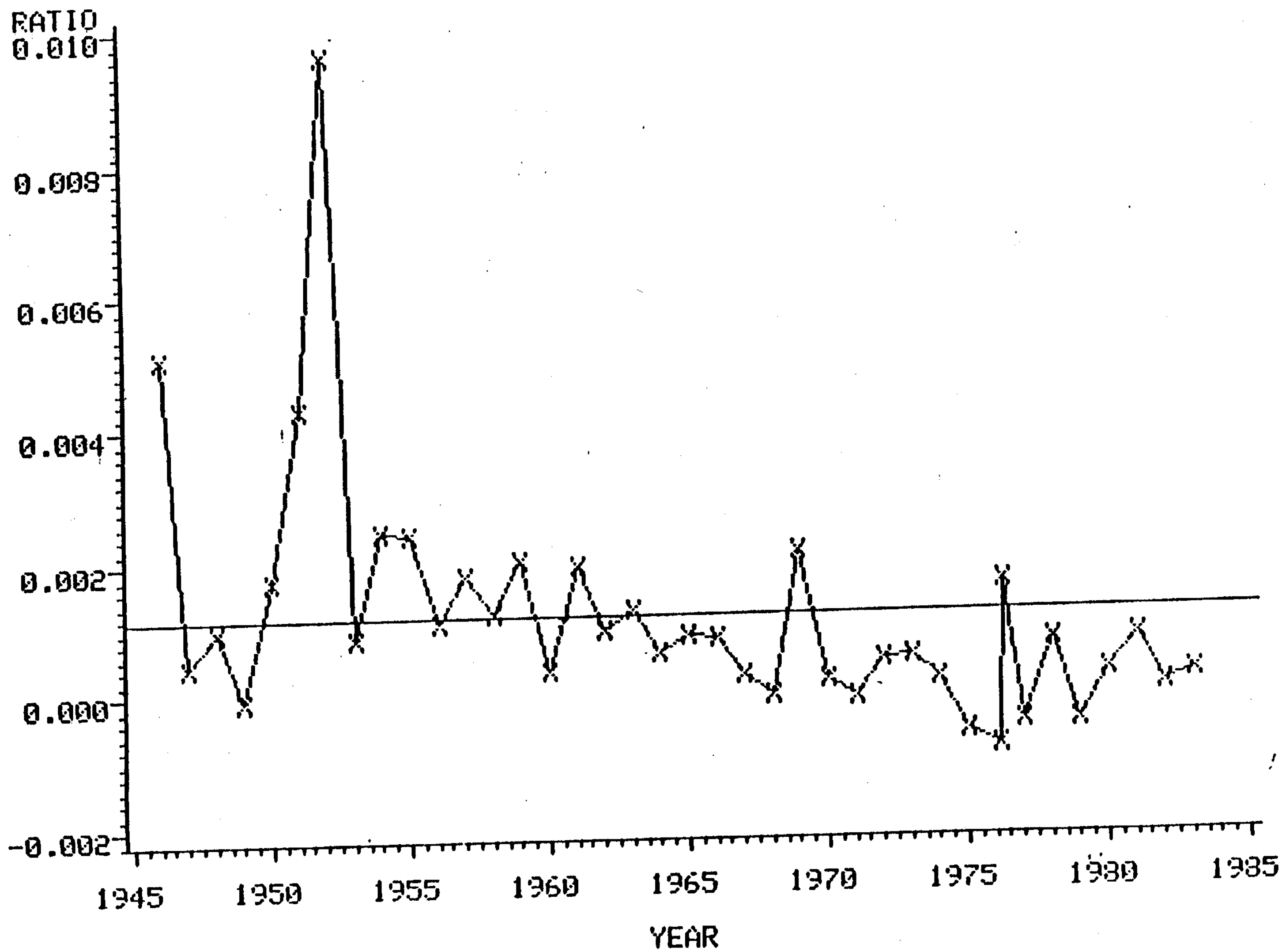


TABLE 6
RATIO OF U235 ID TO OFF AREA RECEIPTS
FOR 1946–1983

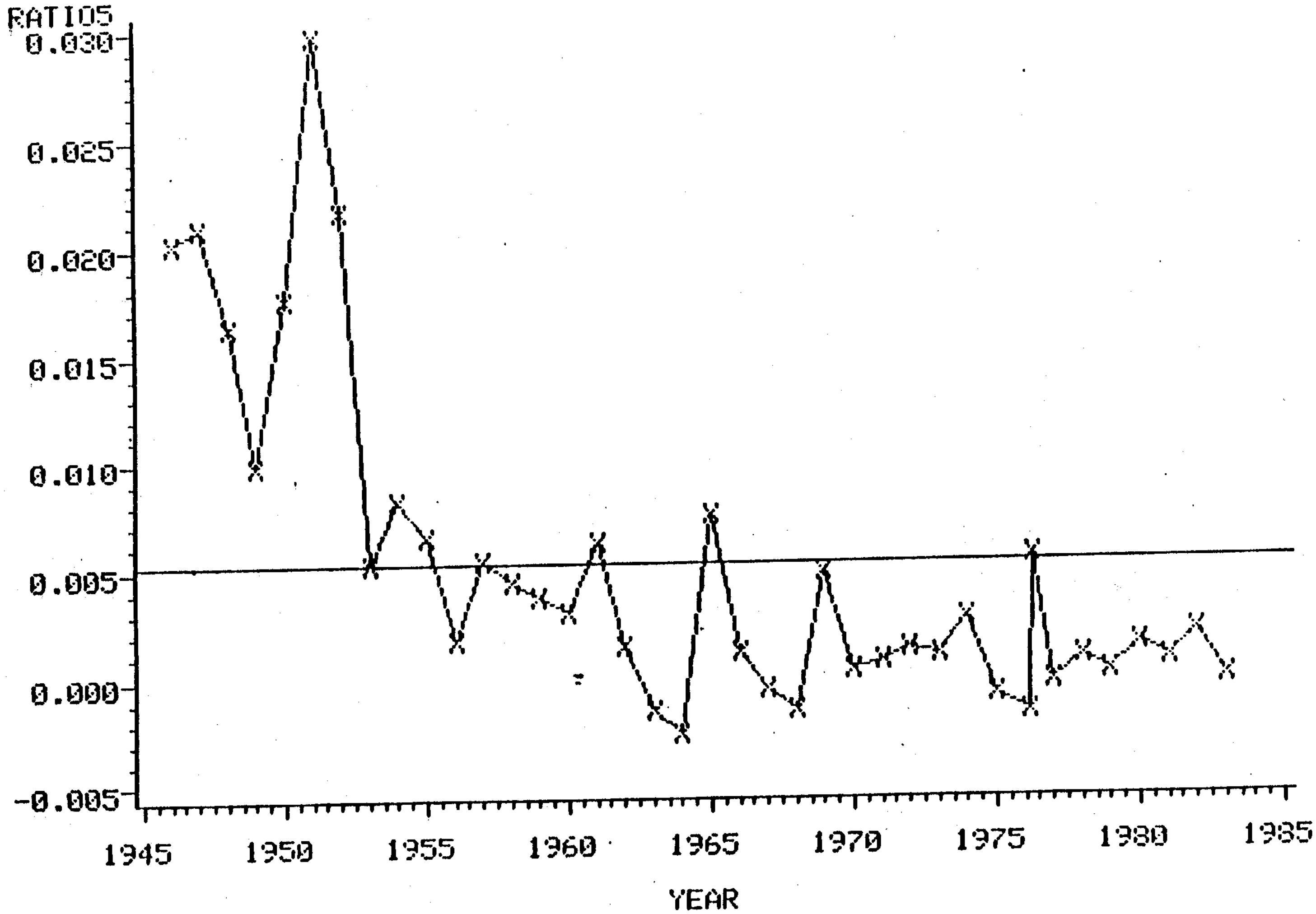


Table 7

EARLY CASCADE GROWTH

(1945 through 1949)

Date	Occurrence
September 9, 1944	First UF_6 received at plant.
January 20, 1945	First cell on UF_6, K-303-3.10. K-25 start up date
February 25, 1945	First unit on UF_6, K-310-2 (8 cells).
March 15, 1945	First product withdrawal, 0.826 percent.
March 19, 1945	First product shipment to Y-12.
September 3, 1945	Last K-25 unit added, K-303-2.
October 18, 1945	Product rate of 8 KgU/day at 23 percent assay.
November 14, 1945	Normal feed assay changed from 0.725 to 0.721 wt. percent U-235.
December 19, 1945	First three K-27 units on UF_6, K-402-3,4,9. K-27 startup
January 1946	Recognition of internal corrosion of equipment by UF_6 as a material balance problem.
January 8, 1946	K-402-6 on UF_6.
January 9, 1946	K-402-5 on UF_6.
January 13, 1946	K-402-1, -2 running.
February 6, 1946	Product assay raised to 30 percent.
February 7, 1946	K-402-7, -8 running; last units to come on line.
July 12, 1946	Product assay raised to 60 percent.
November 4, 1946	Total reflux started to raise assay to 93+ percent.
December 2, 1946	Product withdrawal at 93+ percent.
February 18, 1947	Product assay lowered to 93.5 percent.
October 1947	Problems associated with cascade inventory calculations were recognized and studied.
Early 1948	Barrier Manufacturing Plant started.
Mid to late 1949	Barrier Replacement Program for K-25 and K-27. Decontamination and Recovery of Uranium in converters removed for improvement. Attempt to measure corrosion was not successful.
January 1, 1949	Value of normal changed to 0.7115 percent U-235.
January 28, 1949	Three consecutive inventories taken over a 24-hour period to determine reproducibility.

Table 7 (Continued)

Expansion Period
(1950 through 1954)

Date	Occurrence
July 2, 1950	Complete power failure - No. 1 power transformer burned, main oil circuit breaker failed to trip and isolate fault. Lost motors and seals. Wet air inleakage plugged barrier.
July 20, 1950	Cascade reached 97 percent onstream efficiency after power failure.
Late 1950	Feed Manufacturing Plant started. K-1131 startup
September 29, 1950	First K-29 cells onstream (K-502-1.1 and 2). K-29 start
November 26, 1950	First complete K-29 unit onstream (K-502-1).
December 20, 1950	Second complete K-29 unit onstream (K-502-2).
January 24, 1951	Third complete K-29 unit onstream (K-502-3).
August 6, 1951	First K-31 cells onstream (K-602-4.1,4,6). K-31 Start
December 9, 1951	Last complete K-31 unit onstream (K-602-6).
During 1952	Barrier Changeout Program in K-29 begun.
March 20, 1954	First three cells of K-33 onstream. K-33 Start
September 1954	K-1420 decontamination and recovery facility scheduled for initial operation during this month. K-1420 Start
October 15, 1954	K-311-1 established as side purge at top of K-27. begin c[illegible] K-311-1 purge [illegible]
November 4, 1954	Last complete K-22 unit onstream (K-902-5).
During Period 1950 to 1954	Extensive use of assay dilution technique to measure and verify uranium inventory in select K-25 and K-27 cells.

Table 7 (Continued)

Toll Enrichment and Cascade Improvement Period

(1955 to Present)

Date	Occurrence
Early 1956	Power loads reached 2285 Mw.
January 21, 1957	K-31 Barrier Replacement Program started.
February 1957	Started A-line cooling in K-33. A-line cooling extended to 33 cells in K-33, all 60 cells in K-31, and 15 cells in K-29.
March 1957	All of K-306 section shut down. Later top four units in K-305 shut down.
During 1958	Barrier Replacement Program for K-31 completed.
Late 1961	Feed Plant shut down for the processing of normal and depleted material. K-1131 shutdown
March 1962	Feed Plant reactivated with modified equipment to process slightly enriched uranium material. K-1131 restart
June 1964	All K-25 and K-27 shut down and buffered with nitrogen or dry air. K-25 & K-27 shutdown
July 1965	Feed Plant final deactivation. K-1131 shutdown
Mid-1965	UF_6 Conversion facility in K-1420 deactivated.
June 1964 thru December 1972	Transition period between Military and Civilian Power Program use of cascade production. Characterized by variable power usage and placing much of cascade in standby for extended periods. Cascade production stored for future use in the Toll Enrichment Program. Power usage reached levels as low as 460 Mw.
January 1, 1969	Toll Enrichment Program fully initiated. K-1423 startup
August 1971	Purge cascade incident occurred.
March 1972	ORGDP established as two accountability stations. BWA and FZA.
June 1975	Process Equipment Modification, Cascade Improvement Program/Cascade Uprating program initiated.
January 1977	New top purge facility initiated. K-402-9 start as purge
Fall 1977	Began using non-destructive assay equipment for assay verification.
March 1979	New side purge facility in operation. K-402-8 startup
June 1979	Area power load decreased to 645 MW.
July 1979	K-27 process transformer failure.
September 1979	Power load increased to 1150 MW.
August 1980	New Central Control facility in service.

Table 7 (Continued)

Toll Enrichment and Cascade Improvement Period

(1955 to Present)

Date	Occurrence
April 1981	Installation of four new feed autoclaves in the K-1131 feed vaporization facility.
May 1981	K-29-2.9 release incident.
September 1981	CIP/CUP Program completed.
January 1982	Evaluation of K-31 cascade regional volumes based on CIP/CUP modifications.
June 1982	Orbitron scales in use.
September 1983	Implementation of program for hidden inventory evaluation.

Table 8

LABORATORY HISTORY

URANIUM

METHOD	MATERIAL	DATES	Accuracy +/- 95%C.L.,%
GRAV. (Ni K.O.)	Uranium Hexaflouride	12/48-01/62	0.1
GRAV. (P-10)	Uranium Hexafluoride	01/62-01/82	0.05
GRAV. (P-10)	Uranium Hexafluoride	01/82-Present	0.03
Colorimetric	Alumina	12/48-Present	5.0
Volumetric	U Oxides	12/48-01/81	3.0
		01/81-Present	1.0
X-Ray Fluroescence	Solutions/Solids	10/68-09/72	8.0

URANIUM-235

METHOD	MATERIAL	DATES	Accuracy +/- 95%C.L.,%
Mass Spectrometer	UF_6, 93%	12/48-10/58	0.1
	0.7%	"	0.1
	0.4%	"	0.2
	UF_6, 93%	10/58-10/62	0.02
	0.7%	"	0.1
	0.4%	"	0.2
	UF_6, 3.0%	10/62-Present	0.03
	UF_6, 0.7%	"	0.05
	UF_6, 0.4%	"	0.2
Ionization MS	Solutions/Solids	10/68-Present	1.0
Optical Spectrograph	Solutions/Solids	~64-04/69	2.0

NOTE: THE ABOVE METHODS HAVE NO KNOWN BIAS.

Table 9

Total Plant Inventory Differences

Time Period	Slope in grams per year Uranium	U-235
1946-1951	934,098	93,666
1952-1960	11,070,604	294,091
1961-1968	4,536,495*	26,697*
1969-1974	1,850,893	95,762
1975-1083	800,105	59,997

Cascade Inventory Differences

Time Period	Slope in grams per year Uranium	U-235
1946-1951	525,886	99,514
1952-1960	5,382,423	255,146
1961-1968	1,723,050*	-38,811*
1969-1974	1,817,946	68,046
1975-1978	Not Signif.	----
1979-1983	1,883,815	----
1975-1983	----	65,257

*Data for 1964 omitted.

Feed Plant Inventory Differences

Time Period	Slope in grams per year Uranium	U-235
1950-1966	4,614,640	37,743

TABLE 10

CUMULATIVE URANIUM INVENTORY DIFFERENCES

TOTAL (BLACK), CASCADE (RED), AND FEED PLANT (GREEN) FOR 1946-1983
DIVISIONS AT 1951-52, 1960-61, 1968-69, AND 1974-75

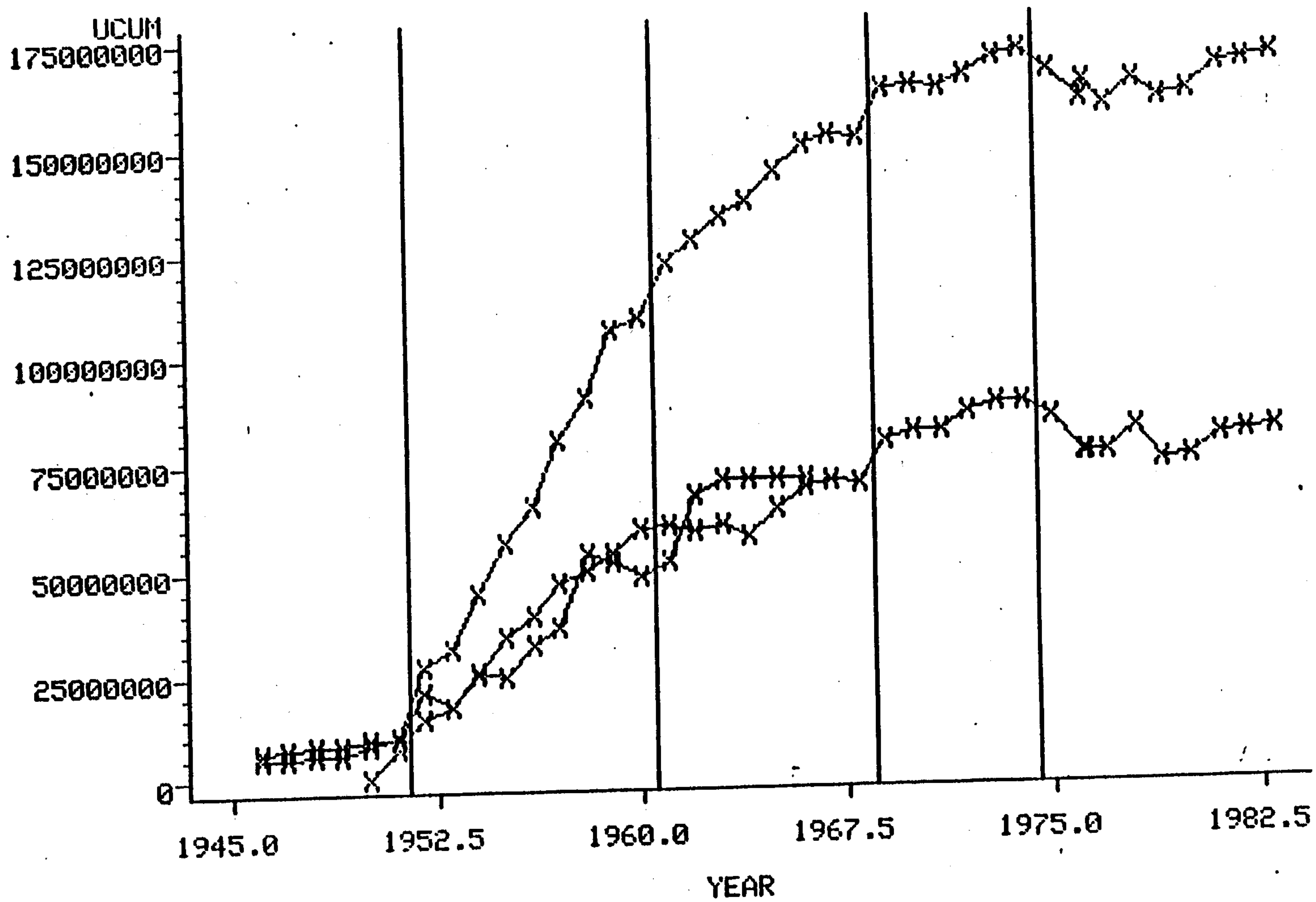


TABLE 11

CUMULATIVE U235 INVENTORY DIFFERENCES

TOTAL(BLACK), CASCADE(RED), AND FEED PLANT(GREEN) FOR 1946-1983
DIVISIONS AT 1951-52, 1960-61, 1968-69, AND 1974-75

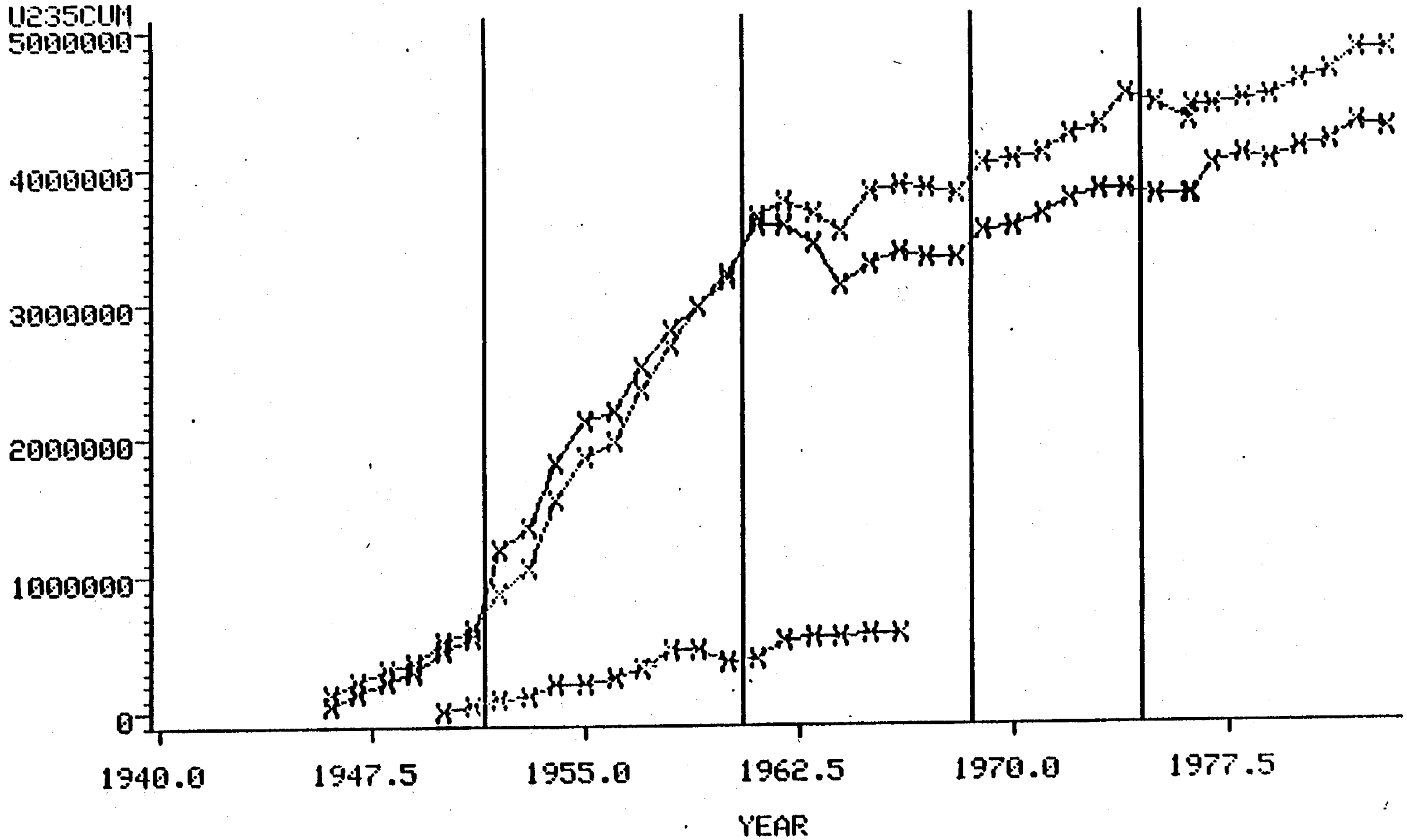
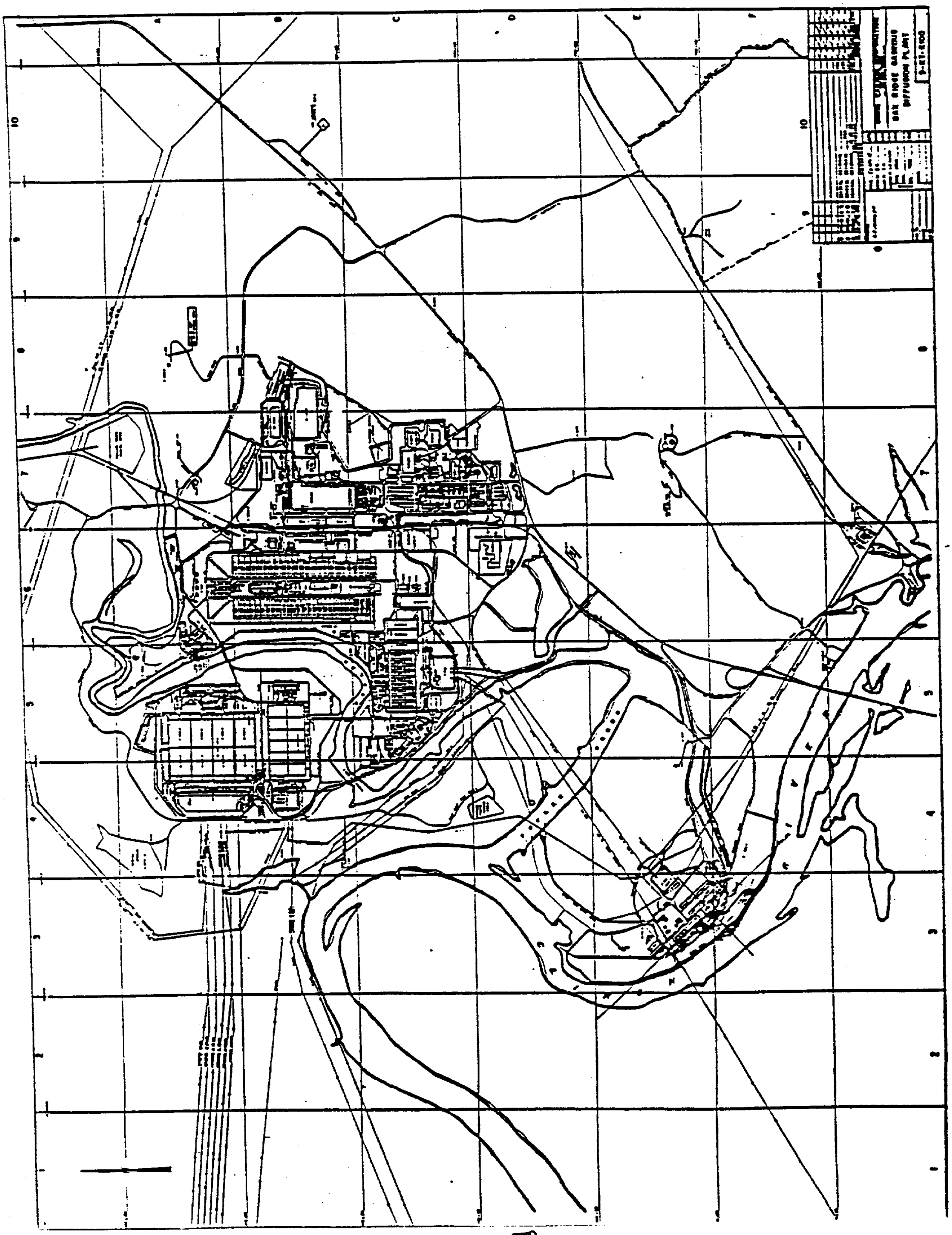


Table 12



DISTRIBUTION

1. K-25 Site Records (RC)
2. ChemRisk/Shonka Research Associates
3. S. G. Thornton (K-25 EMD)
4. DOE Public Reading Room